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THE ECONOMIC FEASIBILITY OF ENHANCING THE FEEDING VALUE OF CANOLA MEALS PROCESSED FROM LOW QUALITY SEED FRACTIONS

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THE OPPORTUNITIES FOR ENHANCEMENT OF CANOLA MEALS AND OILS DERIVED FROM PROCESSING LOW QUALITY CANOLA SEED FRACTIONS

Report Prepared for

MILLIGAN BIO-TECH INC.
and
Saskatchewan Agriculture Development Fund

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EXECUTIVE SUMMARY

The processing of low quality canola seed into canola meal and oil for feed use was investigated. The resulting canola meals are distinctly different from other canola meals available in the industry. The higher oil content and variations in protein degradability set these meals apart.

There are two distinct feed products, oil and protein meal, resulting. Tests with poultry show little or no problems with use of the oil as a feed ingredient. Poultry and swine operations would be the primary target markets for this oil extracted having values approaching that of canola crude now being sold in the industry. Dairy cattle would be a secondary market for oil.

The primary market for canola meal crushed from unheated seed would be for swine and then poultry. For canola seed heated in storage, dairy cattle would be the primary market because these meals have reduced digestibility in monogastric animal diets. Monitoring through analysis of the degree of protein solubility will be needed to differentiate monogastric and ruminant products.

The need for added bypass protein creation in canola meals coming from bin heated seed is of low priority. This added bypass protein capability should be only considered as a small separate facility or in the processing of the seed where it has advantages in oil extraction. The target market for higher bypass canola meal is the dairy industry.

Of greater impact would be the enhancement of the meal to improve protein quality. The use of peas or lentils are an accepted avenue to create unique products for both monogastrics and ruminants. Further, placing some simple blending equipment (proportioner type) and a pelleting mill would enhance capability to use screenings from the plant and other facilities.

The market for these products exist, because of their unique features. Marketing, because of changes within the feed industry, will have to address both feed compounders and also livestock producers.

MILLIGAN BIO-TECH
CANOLA MEAL AND OIL : MARKET OPPORTUNITIES FOR FEED

BACKGROUND: Each year there are thousands of tonnes of lower quality canola produced which is unsuitable for use by crushers. The reasons for this lower quality are due to frost damage, immature seed, drought and heating during storage. The composition of this damaged seed is variable, however past analysis of damaged seed still indicates that a minimum of 80 to 85% of the oil remains and close to the normal protein content. These analyses of lower quality canola seed represent the minimum or lower end of seed quality and are those received by the feed testing laboratory from 1987 to 1994 from producers who generally have no other alternative but to use it as feed. Higher quality, sample canola bought by crushers at discount would have close to normal composition. Capture of the potential of this material through feed products represents the greatest opportunity for maximizing returns. Further, its use as a feed at the farm is hampered by the problem of processing and intermittent availability.

The capturing of value from these seeds will require some form of processing, to create specific products, to negate antinutritional factors and to alter nutrient composition or behavior. The Milligan Biotech process, which is a cold press extraction, separating the canola seed into meal and oil, can with adaptation produce specific feed products and minimize the effects of antinutritional factors. The aspect of altering nutrient content and its behavior should be considered a separate process, only employed after the initial processing into meal and oil. It can be argued that the seed could be left whole, this however will not create the most applicable feed product or optimize profit.

VALUE OF CANOLA OIL AND MEAL: Both the canola meal and oil have value separately and when combined, but not in the same ratio as that originally present in the seed. The following outlines the value and marketability of oil, combinations of meal and oil, and that of enhanced meal through processing.

THE VALUE AND MARKETABILITY OF OIL: Oil will be the most direct of the products being close to a final form resulting from crushing lower quality canola seed. The resulting oil from the extraction process will require little or minimal processing to be

marketed in the feed industry. Filtering to remove coarse particles and the addition of an antioxidant is all that should be required. The filtering process will have to be adequate to allow unhindered mechanical injection in on farm feed milling units. For poultry, oil obtained from this process will have a value equivalent to crude canola oil from the general crushing industry. Studies by Classen and Newkirk 1997, has shown oil utilization and acceptability with chickens to be similar to canola crude oil. Levels of use averaging 3% of total poultry feed are not unreasonable to expect as a market size. Table 1 shows the potential market size for oil in the poultry industry in Western Canada. It should be noted in poultry diets that a minimum of 1% vegetable oil is used to provide a proper balance of fatty acids.

In pork production, oil is used by on-farm mixers to provide an energy source and suppress dust in the feed. As a feed dust suppressant rates of 1% of total feed for all classes is appropriate. As an energy source levels of 3% are appropriate. The value of oil for pork producers will be slightly less than that for regular canola crude. It is expected a small discount plus an assured supply will be adequate to capture this market. Approximately 80% of pigs are fed on farm mixed feed and many large producers have already installed oil holding tanks. This trend to on-farm feed mixing and use of oil at the farm level will continue as it is being driven by economics. In addition, the market access and ability to market within the poultry and swine will increase as production unit size increases.

The value of oil for dairy cows will be equivalent to crude canola feeding oil. Similar to pigs, use by dairy producers will depend on availability. Levels of use of 300 grams per cow per day can be expected to be consumed as an energy alternative to grains. It should be concluded that feed use is a viable alternative for oil use for poultry, swine and dairy cattle, with a total potential market use given in Table 1. Of these swine and poultry which have and used oil, presently will create the initial market and demand.

VALUE AND MARKETABILITY OF CANOLA MEAL: The oil and protein content of the resultant canola meal, along with its nutrient characteristics, will determine value. This canola meal should be thought of as two distinct products, canola oil and canola protein meal each providing its unique value to the product. The oil content of the

canola meal has canola oil equivalent value in swine, poultry and dairy diets. Oil content of the canola meal would restrict its use in diets similar to any other added oil source and would restrict use in dairy diets to 300 grams of added oil. Similarly, there are limits to canola protein meal use in swine and poultry diets while there is no limit essentially in dairy diets. To increase the value and flexibility of canola meal use, oil and protein levels should be matched to those levels most advantageous in the feed. The quality of canola meal needed for pigs and poultry must come from only slightly heated canola or better quality seed to have a higher digestibility of protein for monogastric feed diets. Extensive and severe heating would render some of the protein indigestible by monogastrics such as swine and poultry.

Thus, the process and quality of seed crushed will have an influence on the value and use of the resulting meal. Several test samples of Milligan Bio-Tech canola meal were analysed extensively to describe the protein and carbohydrate fractions. Table 2 lists the analysis of canola meal arising from the Milligan Biotech process in comparison to that of regular canola meal. The Milligan Creek canola meal contains substantially greater amounts of fibre or structural carbohydrate and also fat. To reduce fibre, cleaning the seed prior to oil extraction would help reduce this. The oil content, while high in these samples, are expected to be approximately 10-14% oil in regular production samples. Clearly, the canola meal resulting from this process is different from that of average canola meals. The higher amount of protein, as a % of crude protein attached to the neutral detergent fibre fraction is a result of bin heated seed being used for processing. It is expected that for monogastrics pigs and chickens canola meal from seed not bin heated will have to be used. Of greater concern is when heating of the seed causes a high amount of ADICP fraction. This crude protein attached to the ADF is largely not available to the animal including ruminants. In one sample of canola meal arising from severely bin heated seed, the ADICP as a % of crude protein was 46.9% suggesting that just less than ½ of the total protein would be poorly digested with the meal certainly not suitable for monogastrics. The monitoring of ADICP and NDICP levels will be important in determining product quality and actual target market for the canola meal (i.e. monogastrics vs. ruminants). Please note, an explanation of feed analysis terms is attached to help increase understanding of the meaning of each analysis.

For dairy diets, in addition to oil and protein content, the aspect of providing bypass protein has to be considered. There is a need for a certain level of bypass protein, however meal use will be limited by oil content. Dairy cows in lactation are limited by the amount of oil that can be fed without upsetting rumen metabolism. Again, a balance of oil, protein and bypass protein must be reached. Table 3 shows the value of canola meals with 2 levels of fat and three levels of bypass protein in diets (30%, 45 and 60%) for dairy cows.

From Table 3 it should be noted that for monogastrics, the greatest addition to the meal for value is in the residual oil. For ruminants such as dairy cattle, oil and bypass protein are the driving forces. Increases of 7 to $9 per tonne can be attributed for an increase in oil content from 10 to 14% in the canola meal for dairy diets. The increases attributable for increasing bypass protein are approximately 20 to $25 per tonne as bypass protein, increases from the base 30% to 45% and to 60%. It must be noted that if the demand in the diets increases substantially for bypass protein and there is a significant increase in price per tonne as one goes from 30% bypass protein to 60% bypass protein. However, the 60% bypass protein product is used at a much lower level, with the base animal protein requirements being met with other common protein sources such as regular canola meal. The question then arises how much bypass protein is really needed for maximal feed value capture.

The price of canola oil must at given prices drop below $700/tonne to cause a reduction in the value of canola meals. Because of this the optimum oil level with protein level was found to be close to 14% oil to give the highest value proportionate to its protein level. Processing to this level of 11 to 15% oil would allow flexibility of use in diets. Protein availability for monogastrics (pigs and chickens) is of prime importance. Bin-heated canola may not be suitable for monogastrics but would be suitable for ruminant animals providing additional bypass protein. Samples of meal arising from bin-heated canola showed additional rumen undegradable protein. The added value of additional bypass protein is approximately $25 per tonne of meal (30% bypass vs. 45% bypass), but is more as the demand for bypass protein increases and a higher bypass meal is needed. This small differential questions additional processing at the meal level if only

a slight amount of additional bypass is needed to be created. There may be a means of blending bin-heated canola to provide additional bypass, heating prior to processing or crushing which may not only increase bypass but aid in the oil extraction process, giving other alternatives to a large scale special facility for creating bypass protein.

To create additional bypass protein, heating is the most logical and economic route. To increase handling ease and reduce antinutritional factors pelleting of the meal should be considered. A steam source would be required for the pelleting process. This steam could be used for increasing bypass protein. A temperature of 110°C for 10 minutes is recommended for canola meal which could be accomplished with a steam chamber. If combining with a product such as peas is considered, with a target market for dairy additional bypass protein is needed as peas are low in bypass. Peas need a temperature of 120°C to 125°C for 10 minutes to create added bypass. This would need a small separate facility to provide this level of heating. Equipment to provide this has been suggested by the Agriculture and Bioresource Engineering department to cost approximately $10,000 for a unit separated just outside the main processing facility. The heating of the peas to cause starch gelatinization would also help encapsulate the oil providing a means of oil retention without the leaching effects.

The ability to combine the canola meal with peas (splits and cracks) would be advantageous. For swine diets the peas would provide an improvement in protein quality and a medium to capture the oil and prevent its leaching. Using added peas would also improve pelleting capability. The use of peas and high oil canola meal treated to create bypass protein would provide to the dairy market a specialized feed commodity providing a margin presently of $80 to $95 per tonne over unheated canola meal and peas. This value could be more as ruminant diets move towards consideration of protein quality.

It is expected that for canola meals resulting from unheated higher quality seed, they will be used for monogastrics (swine and poultry). Combining meal with other products such as peas are desirable to improve protein quality. Processing such as mild steam heating to destroy peroxidases and keep the oil in the meal from going rancid should be considered. This steam heating could be combined with a pelleter. Pelleting of high fat

canola meal would be difficult. Before pelleting is considered trials should be done to determine capability of producing a pellet with or without addition of such products as peas. To further support this decision of pelleting, consideration should be given by the plant to producing other feed products such as grain screening pellets from materials available locally.

The use of bin-heated canola seed should be for ruminant diets. Bin heating creates additional bypass protein which could be used as a product by itself without the necessity of the creation of added bypass protein. The most logical direction if quantities of processed meal permits, is the creation of a high value specialized feed product specific for dairy diets. This specialized product is envisioned to be combined with peas and a slight heating process to create added bypass protein. The quantity produced would only be a portion of plant capacity, inferring that the processing facility for heating be of only intermediate or limited capacity.

PRIORITIES OF TARGET MARKETS:

Oil: The greatest demand for oil will be from the poultry industry then followed closely by the hog industry. Both these industries have large specialized units making a stable consistent market for larger quantities of oil and simplifying distribution. The dairy industry is the less desirable market compared to swine and poultry due to lower levels of use and smaller production units. The poultry and swine industries will, however, demand a consistent product related to quality as well as availability.

Canola meal: Much of the canola seed used will be of low quality. However, only that seed which has heated in storage will have reduced protein digestibility for swine and poultry. The largest market for meal coming from canola seed with little or no reduced protein digestibility will be that to the swine industry. Poultry markets will be less apt to adopt the meal because of past perceptions. This, however, will not exclude poultry from the meal but will be a more difficult market to penetrate. The using of peas, whole or recovered splits, or cracks from screenings in a 55% meal to 45% pea blend for swine would make a unique product. This pea-canola mix would distinguish itself by virtue of oil content.

The use of heated canola seed should be that to the dairy industry. Bypass protein of this meal would give it a distinct advantage. Initial estimates indicate a level of bypass in the test meals to be 40-45% of the protein as bypass. This level of bypass is adequate to maximize value in dairy diets. Thus, even with better quality seed only limited quantities of bypass protein need be created. What may be more important beyond a base level of bypass protein is that of protein quality. A 45 to 50% addition of peas to the canola meal would greatly enhance protein quality. Thus, the same product which was not quite suitable for the swine market would do for dairy cow feeding.

For beef cattle beyond a simple energy and protein source there is little or no advantage to having increased bypass protein. Feeding trials as indicated in the literature search show no benefit from bypass protein when all natural protein sources are fed. Benefits, however, do occur from increased protein quality and energy from additional oil. To market the product on any other basis or claims would work for a short term but not have long-term acceptability.

In summary, it should be concluded, that the canola crushing facility should consider the following capabilities or equipment to maximize feed use potential and value.

1. Facilities for grinding - To process such products as peas, grain screenings and collets from processing.
2. A proportional blender - To be placed before the grinder to blend peas or other feed sources with the meal.
3. A heating unit to create added bypass protein on limited quantities of material. Note: This unit is deemed to be separate and only added when quantities warrant.
4. A conditioning steam chamber and pelleter to pellet canola meal and secondary products such as grain screenings.

The accompanying literature search on protein alteration to create additional value in feeds supports the conclusions reached and to the approach of marketing of feedstuffs.

Table 1

Potential of Canola Meal or Oil Use

(tonnes)

	B.C.		Alberta		Saskatchewan		Manitoba	
	CM	Oil	CM	Oil	CM	Oil	CM	Oil
Dairy conc.	21,300	4,680	29,500	5,940	13,200	2,640	14,800	3,360
Pigs		890	89,500	8,950	35,800	3,580	68,900	6,890
	8,900							
Cows		500	19,700	3,800	10,600	2,000	16,000	3,200
	2,300							
Chickens	21,700	6,510	14,200	4,260		1,230		1,920
					4,100		6,400	
Layers		1,600		1,360		580		1,460
	4,800		4,080		1,740		4,380	
Turkey		1,320		1,050		450		900
	4,400		3,500		1,500		2,900	

Assumptions:

Dairy - Oil 200 g/cow/day/305 day lactation = 60 kg

- CM10% of conc.

Pigs (growers) - CM = 10% of feed oil = 1% dust control

Sows - CM = 10% of feed oil = 2%

Chickens = average 3% of feed, oil CM = 10%

Layers = average 2% of feed oil CM = 6%

Turkey = average 3% of feed oil Cm = 10%

Table 2. Canola meal Comparison of Milligan BioTech vs. Regular Canola Meal (Dry matter basis)

	Milligan Bio Tech Canola Meal	Regular Canola Meal
Moisture %	8.33	10.0
Total ash %	7.43	8.61
Fat (ether extract) %	17.36	4.84
Crude protein %	31.38	37.27
ADF %	26.35	19.91
NDF %	47.37	27.39
NPN % SCP	92.20	75.81
SCP % CP	11.32	32.38
NDICP % CP	55.59	17.06
ADICP % CP	17.54	7.05
Total starch %	0.19	2.03
ADL % of NDF	26.83	32.30

NOTE: For explanation of terms please see attached sheets.

Table 3. Value of Canola Meal in Dairy and Swine Diets

Feed	Oil Content of Canola Meal	
	10% Oil	14% Oil
Dairy Concentrate:		
M. Bio CM (30% bypass)	234.91	242.29
M. Bio CM.BP. (45% bypass)	258.13	267.94
M. Bio CMBP60 (60% bypass)	274.25	284.37
Swine Feed:		
Grower	-	235.26
M. Bio C.M.		
Sow diet:	-	261.79
M Bio C.M.		

Basis:	$/tonne		$/tonne
Barley	110.00	Corn gluten meal	580.00
Distillers grains	280.00	Canola oil	900.00
Limestone	120.00	Canola meal	220.00
1:1 mineral	560.00	Meat meal	400.00
Hog min-vit premix	600.00	Tallow	460.00
Wheat	135.00	Peas	220.00
Soybean meal	360.00	Lysine	4100.00

:

EXPLANATION OF TERMS USED IN ANALYSIS OF FEEDS:

Moisture % — Moisture content of samples expressed on an as received basis and on a 100% dry matter basis.

Ash % — The total mineral content of sample. Ash is determined from the total residue left after organic matter is burnt off in a high temperature oven (ashing oven).

Fat (E.E.) % — This is the fat or oil in a sample determined by extracting with ether. (E.E.) refers to ether extract as the method.

Crude protein or C.P. % — Protein determined by analysing the sample for nitrogen content. Since protein is approximately 16% nitrogen, the nitrogen content of the feed is multiplied by a factor of 6.25 to give % protein in a sample (Note 100 ÷ 16 = 6.25 gives factor).

ADF % — Acid detergent fibre is the fibre in a sample which is relatively indigestible by animals. It includes most of the lignin and cellulose fractions of the fibre.

NDF % — Neutral detergent fibre is all the structural fibre in the sample. It includes the lignin and cellulose which is indigestible and the hemicellulose which can be digested by fermentation in the rumen. Note: For monogastrics such as pigs, the NDF portion is relatively indigestible.

NPN (% of S CP) — Non-protein nitrogen expressed as a percentage of total soluble crude protein. Soluble crude protein fraction is that protein portion which is soluble in a buffer solution. The feed is then also analyzed for the amount of nitrogen that does not exist as protein. An example of NPN is urea. NOTE: All NPN is included in soluble crude protein fraction.

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ADL (% of NDF) Acid detergent lignin content expressed as a percentage of neutral detergent fibre (amount of lignin as portion of NDF), lignin is not digestible.

SCP (% of CP) Soluble crude protein portion expressed as percentage of total crude protein (Note: Soluble crude protein degrades rapidly in rumen).

NDICP (% of CP) Neutral detergent insoluble crude protein expressed as a percentage of crude protein. This is the protein bound to the NDF portion and must be fermented to be utilized. NOTE: For ruminants this would contain most of the rumen undegradable portion of the protein or bypass protein.

ADICP (% of CP) Acid detergent insoluble crude protein expressed as a percentage of crude protein. This measures the crude protein bound onto the ADF fraction and is relatively indigestible even by ruminants. A high value could mean excessive heat damage where the protein is not only bypass protein but is not digested or utilized at all.

Total starch That portion of the carbohydrate that exists as starch.

NSC Non-structural carbohydrates are those carbohydrates that are not part of the cell wall structure of the plant and include starches and sugars. On a dry matter basis it is calculated by 100-CP-NDF-fat (E.E.)-ash.

Starch as % of NSC = starch expressed as a % of non-structural carbohydrate.

A LITERATURE REVIEW ON METHODS USE TO PROTECT CANOLA MEAL PROTEIN FROM RUMEN DEGRADATION

By

A. F. Mustafa, J. J. McKinnon and V, J. Racz

I- Introduction:

Protein requirements of ruminants are met by microbial protein that are synthesized in the rumen, dietary protein that escapes rumen degradation and endogenous protein (Clark et al. 1992). Dietary protein requirements for ruminants are usually expressed in terms of ruminal degraded (RDP) and ruminal undegraded (RUDP) protein (NRC 1989). To achieve maximum productivity, a combination of RDP and RUDP should be fed especially for rapidly growing ruminants and highly producing diary cows. In such situations microbial protein production is often insufficient to meet animal requirements (Owens and Bergen 1983). Eck et al. (1988) reported that incoming feeder cattle require 60% of dietary protein in form of RUDP for maximum performance. Matras et al. (1990) found that nitrogen utilization by growing lambs was greatest when 50% of the dietary protein escaped rumen degradation. For dairy cattle producing more than 30 kg milk daily, 36-38% of dietary protein should be in the form of RUDP (NRC 1989). Ruminant requirements for RUDP can be satisfied by feeding dietary proteins with naturally low rumen degradability (i.e. corn gluten meal, brewers grain and dehydrated alfalfa) or by feeding a highly degradable dietary protein which has been protected from ruminal microbial degradation (Owens and Bergen 1983; Windschitl and Stern 1988; Griffin et al. 1993).

Canola meal (CM) is the most common dietary protein source for ruminants in Canada. Like soybean meal (SBM) protein, CM protein is rapidly degraded in the rumen and thus consider a mediocre source of RUDP (Ha and Kennelly 1984 and Kirkpatrick and Kennelly 1987). Feeding CM as a sole dietary protein source might not satisfy the protein requirements of high producing lactating dairy cows and rapidly growing

ruminants (NRC 1989 and NRC 1984). Different physical and chemical methods have been researched to reduce the ruminal microbial degradation of CM and thus increase the amount of protein available postruminally. The objective of this review is look at different methods which have been used to protect CM protein from rumen microbial degradation and show how these methods affect animal performance.

II- When to protect dietary protein:

The main objective of protecting dietary protein is to increase the amount of amino acids available postruminaly and /or change the amino acid profile so that more of the most limiting amino acids will be available to the animal (Crooker et al. 1982). Dietary protein that escapes rumen degradation should provide an amino acid profile that complements the amino acids supplied by rumen microbes (Ørskov 1988). Thus any improvement in animal performance will depend on how successful the protection method is in providing amino acids which are inadequately supplied by rumen microbes. If protection results in providing amino acids which are already supplied in adequate amount by rumen microbes, little or no improvement in animal performance should be expected. A protection method should not interfere or reduce microbial protein production and emphasis should focus on optimizing rumen conditions to maximize microbial protein yield (Crooker et al 1983). Windschitl and Stern (1988) found that feeding lignosulfonate treated SBM did not increase duodenal N flow compared with untreated SBM even though protein degradation was decreased by such treatment. They attributed the lack of response to a reduction in duodenal microbial flow suggesting that a

readily fermentable source of N should also be included in diets containing protected protein.

III- How to test the effectiveness of protection methods:

a) Laboratory analysis:

Different techniques can be used to measure the effectiveness of the methods to protect dietary protein from rumen degradation. Protection of dietary protein is usually accompanied by changes in composition (Table 1). for instance, a proper heat treatment is associated with a reduction in soluble protein, an increase in the amount of N associated with neutral detergent fiber (NDIN) with little or no increase in the amount of N associated with acid detergent fiber (ADIN) (Moshtaghi Nia and Ingalls 1991 and McAllister et al 1993). A considerable increase in ADIN level is usually used as an indicator of over-protection (McKinnon et al 1991 and Lindberg et al 1982). *In Viro* techniques such as *in vitro* ammonia production (McAllister et al 1993 and Khorasani et al 1989) and *in vitro* protease degradation (Khorasani et al 1993) can also be used.

b) In Situ (nylon bag) Technique:

The nylon bag technique is by far the most common method used to test the effectiveness of any protection method (Mir et al, McKinnon et al.; Khorasani et al.; Moshtaghi Nia and Ingalls 1991 and McAllister et al. 1993). The technique is considered a relatively economic and fast method to test the effectiveness of a protection method, in protecting dietary protein from rumen degradation. A major disadvantage of the nylon bag technique is that it can not differentiate between adequate and over-protected protein.

To overcome this disadvantage, the mobile nylon bag technique can be used to measure the post-ruminal availability of the protected dietary protein (McKinnon et al. 1993 Khorasani et al. 1993 and Moshtaghi Nia and Ingalls 1992).

c) Animal performance:

The ultimate and most important test of any protection method is animal performance. For any protection method to be economically feasible, an improvement in animal performance should be achieved. Tamminga (1979) showed that increasing the amount of methionine reaching the small intestine increased wool production in sheep. Kung and Huber (1983) found that feeding ammoinated silage and heated SBM to dairy cows in early lactation resulted in more milk yield compared to feeding unheated SBM. However several studies showed no improvement in animal performance when protected dietary protein was fed to dairy cows (Rae et al. 1983; Crooker et al. 1983; Kennelly and Khorasani 1993 and Jones 1993). Failure to increase productivity by feeding RUDP can be attributed to different factors including reduction in biological value of treated protein (Mir et al. 1984), reduction in microbial protein synthesis due to low availability of ammonia and peptides (Windschtl and Stern 1988 and Clark et al. 1993), small contribution of dietary protein to the total amount of protein that passes to the duodenum (Clark et al. 1993) and overestimation of rumen degradability of highly degradable protein supplements such as CM and SBM when fed to ruminants consuming large amount of feed (Ørskov 1988). Zinn and Owens (1983) indicated that the amount of dietary protein that escapes rumen degradation might be increased by 6.5% for each 10% increase in feed intake. In addition to feed intake, type of diet fed can also affect rumen

degradation of dietary protein. Feeding high concentrate diets such as those fed to highly producing dairy cows and rapidly growing ruminants reduce ruminal protein degradation and thus increase the amount of RUDP (McAllister et al. 1993). Another factor which might explain the lack of response from feeding RUDP is the difficulty to manipulate the amino acid profile of digesta entering the duodenum (Crooker et al. 1983). Clark et al. (1993) indicated that in order to alter the amino acid profile of digesta entering the duodenum, RUDP should provide 50% or more of the total dietary protein which makes such practice uneconomical.

IV- Methods of protecting dietary protein from rumen degradation

Methods of protecting dietary protein from rumen degradation can be classified into:

1- Physical methods:

a) Heat treatments which include dry heat, moist heat (autoclave) and Jet-sploding.

b) Coating with materials that resist rumen degradation (e.g. blood, whey protein, casien).

2- Chemical methods:

a) Chemicals that combine with protein (e.g. formaldehyde, tannin).

b) Chemicals that denature protein (e.g. NaOH, HCl, ethanol).

3- Physio-chemical methods:

a) Non-enzymatic browning (e.g. lignosulfonate + heat).

1. Heat Treatments:

Heat treatment is one of the most common methods used to reduce ruminal protein degradation and to increase the postruminal amino acid supply (Griffin et al. 1993; Stutts et al 1988; Faldet et al. 1991; Mir et al. 1984; McKinnon et al. 1991 and Moshtaghi Nia and Ingalls 1992). Heat treatment is based on the fact that dietary protein consists of different fractions which respond differently to various heat inputs (temperature x time). Soluble protein fraction denatures at lower heat inputs but still is digestible while insoluble but digestible protein fraction respond at higher heat inputs and usually becomes heat damaged via Maillard reaction (Van Soest 1987). An optimum heat treatment or heat input varies from one dietary protein to another and has as its objective to minimize the soluble fraction and maximize the insoluble but digestible fraction with little or no increase in the indigestible fraction (Figure. 1). The optimum heat input depends on several factors including moisture content, pH, carbohydrate content and composition, protein content and the presence of Maillard reaction-inhibiting materials such as sulfite (Van Soest 1987). Methods of heat treatment can be divided into three major methods;

1.1. Dry heat treatment (oven heat).

1.2. Moist heat treatment (Autoclaving).

1.3. Jet-Sploding.

1.1. Dry heat treatment:

This method was one of the first methods tested to protect CM protein form rumen degradation. Early work of Mir et al. (1984) showed that heating CM to 110 °C for 2 h or to 120 °C for 20 min markedly reduced effective crude protein degradability (ECPD) of CM. The study also showed that heat treatment to 110 °C for 2 h reduced ECPD of canola seed without any effect on that of soybean meal (Table 2). The results of that study was one of the early indications that heat temperature is more important than heat duration in protecting CM protein from rumen degradation. Lindberg et al. (1982) studied the effect of different temperature and duration of heating (heating to 100, 150 and 200 °C for 1 h) on *in situ* DM (DMD) and CP (CPD) disappearances of rapeseed meal. They found that heating to 100 °C had no effect on DMD or CPD. However, DMD and CPD was reduced by heat treatment above 100 °C. They also found that increasing heat temperature from 100 to 150 °C increased ADIN proportionately more than increasing the rumen undegraded protein. This might indicate that although such heat input was effective in protecting protein from rumen degradation, it might have resulted in heat-damaged rather than RUDP. However in both of the above studies no data were available regarding the effect of those treatments on intestinal availability and total tract digestibility of the heat treated protein.

The effect of short-term heat input on CM protein has been studied by McKinnon et al. (1991). In the study, high temperatures (125 and 145 °C) were tested for short periods of time (10, 20 and 30 min). The results indicated that heating CM to 125 or 145

°C for 10 min or more reduced DMD and CPD. At 125 °C, the proportional increase in RUDP was more than the increase in ADIN. However, at 145 °C the proportional increase in ADIN was more than RUDP. Using nylon bag technique, McKinnon et al. (1993b) determined postruminal and total tract availability of DM and CP for heated CM used in their previous study. Relative to untreated CM, heating CM to 125 °C reduced ruminal DMD and CPD, increased intestinal DM disappearance without affecting total tract disappearance of DM and CP. In contrast, heating CM to 145 °C resulted in reduced intestinal and total tract disappearance of DM and CP relative to untreated CM (Table 3). The study also showed that temperature was more important than heat duration. It was concluded that dry heat treatment of CM to 125 °C up to 30 min is an effective method for increasing RUDP of CM without affecting the quality of protein available postruminaly. However, heating to 145 °C resulted in heat-damaged protein with lower intestinal and total tract digestibility.

In another experiment McKinnon et al. (1993a) examined the performance of feedlot cattle fed different types (heated CM and corn gluten meal) and levels (22, 28, 32 and 34%) of RUDP. The results of the experiment showed that daily gain of calves fed 28% RUDP were higher than of those fed 22% RUDP. However, over the entire course of the trial no difference was observed between the different levels of RUDP. The results also showed no benefits from feeding heated CM or corn gluten meal over untreated CM to feedlot cattle fed from weaning to slaughter (Table 4).

Jones (1993), studied the effects of short-term heat treatment (125 °C for 20 min) on effective degradability of DM and CP of CM and canola presscake (CPK). He found

that heat treatment reduced effective degradability of CP of CM and CPK by 56 and 33%, respectively . The corresponding reduction in effective degradability of DM was 36 and 19%, respectively. Feeding heated CM or CPK at 22% of the concentrate diet resulted in an increase in milk protein yield and total milk yield in heifers with no similar effects on multiparous cows. However, when heifers and cows were combined, heated treated protein supplements did not have any advantage over untreated ones (Table 5).

1.2. Moist heat treatment:

Moist heat treatment (autoclave) is an alternative technique to dry heat treatment. It is usually used to dry CM during the extraction process in crushing plants. Moshtaghi Nia and Ingalls (1992) moist heated CM at 127 °C with steam pressure of 117 kPa for 15, 30, 45, 60 and 90 min. They found that moist heat treatment decreased ruminal degradability, increased intestinal availability without adversely affecting total tract digestibility of either DM or CP (Table 6).They also found that moist heat treatment of CM for 45 min. or more reduced total tract CP disappearance relative to untreated CM.

The influence of moist heat treatment on ruminal and intestinal disappearance of amino acids from canola meal were studied by Moshtaghi Nia and Ingalls (1995). In the study canola meal was moist heated at 127 °C for 15 and 45 min. The authors reported that moist heat treatment for 15 or 45 min reduced the concentration of lysine by 15.9 and 29.2%, respectively and that of arginine by 8.0 and 15.2%, respectively. The concentration of other amino acids was not affected by heat treatment. Moist heat treatment was found to reduce the degradation of amino acids in the rumen and to

increase the availability of amino acids for intestinal digestibility (Table 7). The authors observed that heating for 15 min was less harsh than 45 min heating. The increase in disappearance of amino acids in the small intestine by heating for 15 min versus that of heating for 15 min ranged from 75% for lysine to 154% for histidine.

From the results of these studies, it can be concluded that moist heat treatment for 15 or 30 min is an effective method for protecting canola meal protein form microbial degradation in the rumen. This results in substantial increases in amino acids available for intestinal digestibility. Further studies are warranted to investigate the effect of shorter heating periods (i.e. less than 15 min) on protein quality of canola meal and also to study the effect of feeding moist heated canola meal on animal performance.

1.3. Jet-Sploding:

Jet-Sploding is a heat treatment which involves rapid steam heat treatment under high pressure for short period of time utilizing the moisture within the seed. The length of time the seed remains inside the jet-sploder and the temperature applies depend on the targeted internal seed temperature. The process was used to increase RUDP of whole canola seed (WCS) and has been described by Kennelly et al. (1993). Deacon et al. (1988) compared ruminal degradability and intestinal digestibility of DM and CP of jet-sploded whole canola seed (JSWCS) sploded at 121 °C internal seed temperature to other protein sources. Those included unprocessed WCS, extruded WCS, CM and extruded CM. The results showed that Jet-sploding reduced effective degradability of DM and CP

of JSWCS relative to unprocessed WCS . However total tract digestibility of DM and CP were higher in unprocessed WCS relative to JSWCS (Table 8).

Kennelly et al. (1993) studied the effects of including graded levels of JSWCS (jet sploded at 150 °C) on milk yield and milk composition of early and mid to late lactation dairy cows. They reported that inclusion of JSWCS up to 4.5% of the diet in early lactation had positive effects on milk yield while no benefits were obtained from adding JSWCS on diets of mid to late lactating cows. Inclusion of JWSCS in dairy rations depressed milk protein concentration and altered milk fatty acid composition. As the inclusion rate of JSWCS increased the concentration of C16:0 decreased while that of C18:1 increased with no effect of inclusion rate on the concentration of C18:2 or C18:3.

1.4. Summary and conclusions:

1- Dry or moist heat treatments at high temperature for short duration seem to be effective in protecting CM protein from rumen degradation without reducing intestinal protein availability or total tract digestibility. The methods have the advantage of being used in the crushing plants during oil extraction and can be manipulated to achieve different levels of protection.

2- Most of the studies conducted for heat treatment of CM have shown little or no animal response and several studies have not been supported by animal performance data. Lack of response might be due to a reduction in the amount of dietary protein needed to

maximize microbial protein yield and / or failure to alter the amino acid profile of protein reaching the duodenum.

3- Further studies should be conducted to determine the changes in amino acid profile of heated CM reaching the duodenum and whether heat treatments will result in supplying more of the limited amino acids for growing ruminants and dairy cows.

2. Chemical Treatment:

Various chemical methods have been used to protect dietary protein from rumen degradation (Sharma and Ingalls 1974; Rae et al. 1983; Mir et al. 1984; Khorasani et al. 1993; Crooker et al. 1983; Varvikko et al. 1983; Waltz and Stern 1989) . Chemical treatments can be divided into two categories; treatments in which the chemicals combine with the protein (e.g. formaldehyde) and those in which the chemicals alter the protein structure by denaturization (e.g. NaOH and propionic acid). Chemical from the first group form reversible cross linkages with amino and amide groups which decrease protein solubility in the rumen and make protein available postruminaly by breaking the linkages enzymaticaly under the acidic condition of the abomasum (Van Soest 1987). While reducing protein solubility, unlike heat treatments, chemical treatments do not alter the protein structure so drastically that more of the protein will be soluble in acid detergent solution (Table 9).

2.1. Formaldehyde treatment:

Formaldehyde (HCHO) treatment is by far one of the most common method used to protect dietary protein from rumen degradation. It acts by forming 'leather-like' substance which resists rumen microbial degradation. Reversible linkages are usually formed between the active side chain of amino acids such as lysine and the carbonyl group of formaldehyde (Antoniewicz et al. 1992 and Waltz and Stern 1989). However irreversible cross linkages are also possible due to overprotection. Treating SBM with HCHO decreased rumen protein degradation, increased *in vitro* total and essential amino acid flow (Waltz and Stern 1989). Although HCHO treatment is considered as one of the most effective method of protecting protein, HCHO treated SBM is usually less digestible (Vicini et al. 1983) with little or no animal response (Stanton et al. 1983 and Crooker et al. 1983).

Similar to other protection methods, HCHO reduces rumen degradation of dietary protein by reducing the soluble fraction and the rate by which the potentially degradable fraction degrades (Table 10). Early work of Sharma et al. (1974) showed that HCHO treatment (0.7 g / 100 g CP) of rapeseed meal (RSM) did not increase the flow of total nitrogen, non ammonia nitrogen or the concentrations of amino acids leaving the rumen. They concluded that HCHO treatment was less effective in RSM compared with casien. Baily and Hironaka (1984) found that treating RSM with HCHO (0.5 g / 100 g CP) resulted in marked reduction in effective degradability of different nutrients. Eeefctive degradability of total nitrogen, insoluble N and non protein organic matter for HCHO -treated RSM were 21, 6 and 34%, respectively. The corresponding values for untreated RSM were 82, 58 and 57%, respectively. The effect of different concentrations of HCHO on *in situ* CP degradability of rapeseed meal has been investigated by Setälä

and Syrjälä-Qvist (1984). They observed a drastic reduction in rumen degradation of CP as the level of HCHO increased. They also found small differences the concentration of amino acids between the undegraded residues and the original samples and the differences were further reduced by HCHO treatment (Table 11). Similar results were also reported by Varvikko et al. (1983). These results indicated that HCHO treatment did not alter the amino acid profile of RSM.

The effect of HCHO treatment (0.8 g / 100 g CP) on protein quality of CM, canola seed (CS) and SBM has been studied by Mir et al. (1984). Although HCHO was very effective in reducing the ECPD of CM, CS and SBM, it was found to have a detrimental effect on true digestibility of the resulting protein (Table 12). The authors concluded that overprotection of the protein is due to the formation of irreversible cross linkages which are resistant to enzymatic digestion. Antoniewicz et al. (1992) estimated intestinal CP availability of lupines, peas, rapeseed meal and field beans treated with 0, 0.1, 0.2, 0.3 and 0.4 g / 100 CP HCHO. Although HCHO treatment was more effective in reducing ruminal CP degradability of RSM and lupines, except for RSM all protein sources exhibited complete compensation of intestinal CP digestibility. The authors attributed the reduction in intestinal digestibility of HCHO-treated RSM to the formation of irreversible links between tyrosine and formaldehyde (electrophilic aromatic substitution).

Rae et al. (1982) studied the effect of feeding HCHO-treated CM (1.2 g / 100 g CP) to Holstein cows in early lactation. No effect of HCHO-treated CM was observed on feed intake, milk yield or milk composition (Table 13). The

author concluded that HCHO treatment might have reduced the availability of specific amino acids particularly tyrosine and lysine, whose availability might have limited milk yield. Supplementation of HCHO treated CM with tyrosine (50 g / cow/ day) was found to increase milk yield by 3.4%. It can be concluded that although formaldehyde treatment of CM was very effective in reducing rumen degradation, the process seems to have adverse effects on protein quality which resulted in reduced digestibility and lack of animal response.

2.2. Other chemicals:

Acid (e.g. hydrochloric, acetic and propionic acid) and alkali (e.g. sodium hydroxide)treatments have also been used to reduce rumen degradation of protein supplements. Waltz and Loerch (1986) found that acid (2.5 and 5% propionic or acetic) and alkali (0.5 N NaOH) treatment of soybean meal reduced *in vitro* NH_3-N accumulation and *in situ* CP degradability without affecting total tract digestibility. Treating SBM with 0.5 N NaOH resulted in a 39% increase in N retention in lambs compared to untreated SBM. In contrast to those results, Waltz and Stern (1989) reported that treating SBM with NaOH (5% of DM) and ethanol had no effect on *in situ* CP degradability.

Mir et al. (1984) showed that treating CM with 50% NaOH solution (3g / 100g CP) reduced effective degradability of CP without affecting true protein digestibility compared with untreated CM. Khorasani et al. (1989) studied the effects of treating CM with different chemicals on *in situ* CP degradability and true CP digestibility. Treatments included spraying with hydrochloric, acetic,

formic and propionic acid at 2.5 and 5% (v / w) followed by drying at 105 °C for 20 h. All chemical treatments were found to decrease *in situ* CP degradability without adversely affecting true CP digestibility except for hydrochloric acid treatment. In contrast to these results, McKinnon et al. (1991) indicated that treating CM with acetic or formic acid (30 mL kg^{-1} DM) had no effect on *in situ* DM or CP degradability. The positive effect of acid treatment reported by Khorasani et al. (1989) might be due to the combination of heat and acid treatment rather than the acid treatment alone.

Based on their previous study, Khorasani et al. (1993) treated CM with 3% acetic acid in large scale to study the effect of such treatment on rumen kinetic parameters and effective degradability of DM and CP. The results showed that acetic acid treatment reduced *in situ* degradability by reducing soluble fraction and decreasing the rate of degradation of the potentially degradable fraction of DM and CP (Table 14). The effect of such treatment on milk yield and milk composition of mid lactation (experiment one) and early lactation (experiment two) dairy cows were then investigated. Results of the first experiment indicated that replacing untreated CM with acid treated CM at 0, 33, 67 and 100% in the concentrate part had no effect on milk yield or milk composition (Table 15). However, replacing untreated CM with acid treated CM at 0, 50 and 100% in the concentrate part in experiment two tended to increase milk yield without affecting feed intake or milk composition (Table 16).

2.3. Summary and conclusions:

1- Chemical treatments of canola meal protein produced inconsistent results and seem to be less effective than heat treatments.

2- Some chemical treatments such as HCHO treatment might have detrimental effects on the quality of resulted protein.

3- Cost of chemicals and the necessary modifications in the crushing plants will make such treatments more expensive that heat treatments.

4- As for heat treatments, chemical treatments of canola meal protein showed little or no consistent improvement in animal performance.

5- Any further research on chemical treatments should focus on whether such treatments will modify the amino acid profile of the treated protein.

3. Non-enzymatic browning:

Non-enzymatic browning involves reaction between sugar aldehyde groups and free amino groups in the presence of heat (Windschitl and Stern 1988). Prolonged treatment of protein under conditions that foster browning can result in the formation of indigestible protein while properly controlled one might be an effective method of protecting dietary protein from rumen degradation without reducing protein digestibility. Factors which control non-enzymatic browning include type and the concentration of reducing sugars, temperature and duration of heating water activity and pH of the reaction mixture (Cleale et al 1987c). Data of Cleale et al (1987a,b) showed that controlled non-enzymatic browning reduced rumen protein degradation and improved protein utilization of SBM by ruminants.

Byproducts which contain reduced sugars can also be used to reduce rumen protein degradation. Lignosulfonate is a byproduct of paper and wood industry (Windschitl and Stern 1988). It is derived from the spent sulfite liquor that is generated during the sulfite digestion of wood and contains lignosulfonic acid or its salt (e.g. calcium salt), hemicellulose and sugars. The treatment utilizes wood sugars and heat to elicit Maillard reaction. Lignosulfonate and xylose treatments were effective in reducing rumen protein degradation of SBM.

McAllister et al. (1993) and Cheng et al. (1993) studied the effects of lignosulfonate (LSO_3) treatment on CM protein. Treatments included untreated CM, water-treated CM, 5 or 10% LSO_3-treated CM and 2% xylose treated CM. All treatments were followed by 1 or 2 h heat treatment. Results of the experiments showed that LSO_3 and Xylose treatments of CM reduced soluble protein, in vitro NH_3 release and increased NDIN without a considerable increase in ADIN (Table 17). The LSO_3 treatments were also effective in reducing ruminal CP degradability by reducing soluble protein fraction and decreasing the rate of degradation of the potentially degradable fraction (Table 18). Lignosulfonate treatment of CM protein seems to be a promising protection method. However, more research is needed to determine intestinal availability of the treated CM protein and the effects of feeding such protein to rapidly growing ruminants and dairy cows.

V- Summary and conclusions:

1- Several protection methods were successful in reducing rumen degradation of canola meal protein, increasing the amount of protein available postruminaly without affecting total tract digestibility. However, most of the studies focused on protecting canola meal protein from rumen degradation without looking whether such methods are effective in supplying the most limiting amino acids required by the host animal.

2- Heat treatments seem to be more effective than chemical treatments in protecting canola meal protein from rumen degradation. Some chemicals might have detrimental effects on digestibility of the protected protein.

3- Although many protection methods were effective in reducing rumen degradation of canola meal protein, this reduction has not been shown to improve animal performance. Reasons for that might include; a reduction in the amount of dietary protein required to maximize microbial protein yield, an adequate amount of highly degradable dietary protein may already escape degradation in the rumen particularly in animals at high feed intake and the protection methods might not be successful in altering the amino acid profile of the protected protein. This might result in a protected protein which does not provide the most limiting amino acids and / or provide amino acids which are already supplied in adequate amount by the rumen microbes.

4- Most research data suggest that little or no economic benefits should be expected from increasing rumen undegradable protein of canola meal that now is being marketed.

5 - Research priority should be given to more comprehensive studies dealing with:

- Effect of protection methods on microbial protein yield.

- Effectiveness of such protection methods in altering the amino acid profile of canola meal protein and if such alteration will meet the host animal requirements. Application of this research awaits improved estimation of amino acid requirements of ruminants and also development of more effective identification of performance limitation aspects of the total ration.

6- More research should focus on whether certain amino acids are inadequately supplied by rumen microbes when canola meal is fed under different feeding situation (e.g. beef cattle, dairy cows). Research should also focus on whether the limited amino acids in each feeding situation can be supplied by feeding protein supplements with naturally low rumen degradability e.g. corn gluten meal and brewers grain or simply by adding these amino acids to feeds in protected form.

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Table 1. Effect of moist heat treatment on nutrient composition of canola meal

	Heat treatment (min)					
	Control	15	30	45	60	90
Neutral detergent fiber	24.9	35.3	40.1	48.3	55.7	
Acid detergent fiber	15.8	14.2	15.0	23.3	36.4	
Crude protein (CP)	40.25	40.6	40.3	40.5	40.9	41.1
Soluble CP (% of CP)	32.4a	7.0c	7.6bc	8.1bc	9.3bc	9.7b
Neutral detergent insoluble CP (% of CP)	8.4f	26.3e	35.2d	45.5c	58.4b	70.2a
Acid detergent insoluble CP (% of CP)	5.4d	6.6d	7.0d	19.5c	26.5b	41.1a

a-f Means in the same row followed by different letters are different ($P<0.01$).

Adapted from Moshtaghi Nia and Ingalls (1992).

Table 2. Effect of dry heat treatment on protein kinetic parameters and effective degradability (ECPD) of canola meal, canola seed and soybean meal.

	Kinetic parameters			ECPD
	soluble CP (%)	degradable CP (%)	degradation rate (% h^{-1})	
Canola meal				
Control	27.8	42.8	4.3	47.6a
Heated (110 °C - 2 h)	23.3	37.9	4.4	41.0b
Heated (120 °C - 20 min)	24.4	38.1	3.8	40.9b
Canola seed				
Control	27.9	31.8	3.6	41.2a
Heated (110 °C - 2 h)	23.6	29.5	3.8	36.3b
Heated (120 °C - 20 min)	23.3	37.3	4.5	41.0a
Soybean meal				
Control	31.3	61.7	4.6	60.9
Heated (110 °C - 2 h)	15.1	72.9	7.4	58.6
Heated (120 °C - 20 min)	31.8	58.7	4.5	59.4

a, b Mean in the same column followed by different letters are different ($P<0.05$).
Adapted from Mir et al. (1984).

Table 3. Effect of dry heat treatment on ruminal, intestinal and total tract disappearance of dry matter and crude protein.

		Temperature (°C)					
		125			135		
		Duration (min)			Duration (min)		
	Control	10	20	30	10	20	30
Dry matter							
Rumen	63.1a	45.2b	43.7b	41.7c	32.6d	32.0d	31.2d
Intestinal	51.9b	61.2a	59.4a	61.5a	42.4cd	44.9bd	35.8d
Total tract	82.3a	78.7ab	77.1b	77.6b	61.2c	62.6c	55.9d
Crude protein							
Rumen	64.3a	33.8b	31.0c	30.6c	24.6d	24.9d	19.7e
Intestinal	80.5a	85.5a	83.0a	84.2a	53.1bc	59.3b	48.7c
Total tract	93.0a	90.4a	88.3a	89.0a	64.4bc	69.4b	57.9c

a-e Mean in the same row followed by different letters are different.
Adapted from McKinnon et al. (1993b).

Table 4. Effect of rumen undegraded protein level of performance of feedlot cattle.

	Rumen undegraded protein level (% of dietary protein)			
	22	28	32	34
Dry matter intake (kg d^{-1})				
Day 0 to 56	8.2	8.3	8.0	8.1
Day 0 to finish	8.8	8.9	8.6	8.8
Daily gain (kg)				
Day 0 to 56	1.19b	1.32a	1.26ab	1.21ab
Day 0 to finish	1.28	1.33	1.31	1.29
Feed conversion				
Day 0 to 56	6.95	6.27	6.38	6.71
Day 0 to finish	6.98	6.67	6.69	6.89

a,b Mean in the same row followed by different letters are different ($P<0.05$).
Adapted from McKinnon et al. (1991a).

Table 5. Effect of heat treatment of canola meal and canola presscake on performance of lactating cows.

	Control	Unheated		Heated	
		Meal	Presscake	Meal	Presscake
Day matter intake (kg d^{-1})	20.8	20.2	21.3	20.7	20.5
Yield (kg d^{-1})					
Milk	26.1b	27.7a	27.6a	25.9b	26.9ab
Fat	0.91	0.81	0.81	0.80	0.87
Protein	0.79b	0.81ab	0.84a	0.78b	0.81ab
Lactose	1.26b	1.35a	1.34a	1.25b	1.29ab
Composition (%)					
Fat	3.51a	2.92b	2.92b	3.11b	3.25ab
Protein	3.06	2.96	3.08	3.02	3.01
Lactose	4.84b	4.88a	4.86ab	4.81bc	4.79c

a-c Means in the same row followed by different letters are different ($P<0.05$).
Adapted from Jones (1993).

Table 6. Effect of moist heat treatment of canola meal on dry matter and crude disappearance from different segments of the gastro-intestinal tract of steers.

	Heat treatment (min)					
	0	15	30	46	60	90
			Rumen			
Dry matter	67.8a	42.7b	38.0c	35.4d	34.2d	33.1d
Crude protein	74.4a	30.1b	21.3c	18.9cd	17.3d	17.4d
			Lower tract			
Dry matter	10.1b	35.0a	34.3a	33.0a	30.2a	34.8a
Crude protein	16.2b	56.5a	64.7a	64.2a	61.6a	64.5a
			Total tract			
Dry matter	77.9a	77.1ab	72.3abc	68.4bc	65.2c	68.5bc
Crude protein	90.5a	88.2ab	85.9abc	83.2bc	79.8c	82.4bc

a-d Means in the same row followed by different letters are different ($P<0.05$).

Table 7. Effect of moist heat treatment of canola meal on intestinal availability of individual amino acids after 16 h of ruminal incubation (g / 16 g N).

	Heat treatment (min)		
	0	15	45
Threonine	1.51	3.08	2.81
Valine	1.51	2.83	2.10
Methionine	0.77	1.50	1.58
Isoleucine	1.17	2.22	1.65
Leucine	2.46	5.28	4.84
Phenylalanine	1.46	3.06	2.86
Histidine	0.62	1.55	1.56
Lysine	1.74	3.03	2.49
Arginine	1.61	3.67	3.16

Table 8. Effect of jet-sploding on effective ruminal degradability and total tract digestibility of whole canola seed relative to canola and soybean meal.

	Ruminal degradability		Total tract	
	Dry matter	Crude protein	Dry matter	Crude
Whole canola seed				
Unheated	83.7a	86.7a	91.7a	93.
Extruded WCS	83.7a	86.2a	90.0ab	93.
Jet-sploded WCS	42.6c	60.8c	79.8c	87.
Canola meal				
Unheated	63.6b	66.1bc	80.5c	92.
Extruded CM	65.2b	65.0c	82.4c	93.
Soybean meal				
Unheated	77.4a	68.2b	96.5a	99.
Extruded SBM	75.1a	66.4bc	94.9a	98.

a-c Means in the same row followed by different letters are different ($P<0.05$).
Adapted from Deacon et al. (1988).

Table 9. Effect of acid and alkali treatments on protein fractions and in vitro ammonia accumulation of soybean meal.

	Control	Acetic acid (%)		Propioninc acid (%)	
		2.5	5.0	2.5	5.0
Crude protein (CP)	44.8	45.9	45.3	45.3	43.8
protein solubility (% of CP)	16.2	5.4	10.6	13.1	9.5
Acid detergent insoluble protein (% of CP)	8.5	8.8	9.3	9.9	11.7
Pepsin insoluble protein (% of CP)	10.0	11.3	11.3	12.5	12.5
In vitro NH3-N ($\mu g\ mol^{-1}$)	142.4	99.8	27.7	88.6	44.9

Adapted from Loerch (1986).

Table 10. Effect of formaldehyde treatment on ruminal protein degradability of canola meal.

	Kinetic parameters			
	Soluble fraction (%)	Degradable fraction (%)	Degradation rate (% h^{-1})	Effective degradability (%
Canola meal				
Untreated	27.8	42.8	3.4	47.6
Treated	12.4	19.8	4.0	21.1
Canola meal				
Untreated	24.9	74.5	6.8	65.5
Treated	13.1	44.3	1.3	22.1

z Treated with formaldehyde at 0.8 g per 100 g of CP (Mir et al. 1984).
Y Treated with formaldehyde at 1.5 g per 100 g of CP (Ha and Kennelly 1984).

Table 11. Effect of formaldehyde (HCHO) treatment of rapeseed meal on proportion of essential and non-essential amino acids following rumen incubation.

	Amino acid (% of dietary protein)	
Rumen incubation (h)	Essential	Non-essential
Untreated Rapeseed meal		
0	51.0	49.0
2	53.4	46.6
5	53.0	47.0
9	54.2	45.8
Treated (0.4g HCOH / 100 g of protein)		
0	50.6	49.4
2	49.6	50.4
5	52.8	47.2
9	49.5	50.5
Treated (0.8g HCOH / 100 g of protein)		
0	51.0	49.0
2	52.3	47.7
5	52.0	48.0
9	51.4	48.6

Adapted from Setala and Syrjala-Qvist (1984).

Table 12. Effect of formaldehyde treatment on protein quality of canola seed, canola meal and soybean meal.

	Net protein ratio	True protein digestibility
Canola seed	2.4	67.3a
Untreated unincubated	2.7	69.7a
Untreated incubated	2.7	63.7b
Treated		
Canola meal		
Untreated unincubated	4.1a	84.6a
Untreated incubated	3.5a	85.1a
Treated	3.8b	71.3b
Soybean meal		
Untreated unincubated	4.0a	87.9a
Untreated incubated	4.2a	83.4a
Treated	2.6b	59.9b

a, b Means in the same row followed by different letters are different ($P<0.05$).
Adapted from Mir et al. (1984).

Table 13. Effect of protein level and formaldehyde treatment of canola meal on feed intake, milk yield and milk composition of lactating cows.

	Protein level		Formaldehyde treatment	
	17.4	14.6	Treated	Untreated
Feed intake (kg d^{-1})	19.5	18.3	19.0	18.7
Yield (kg d^{-1})				
Milk[z]	33.2	30.4	31.2	32.4
Fat[z]	1.3	1.2	1.3	1.3
Protein[z]	1.0	0.9	0.9	1.0
Lactose[z]	1.6	1.5	1.5	1.6
Milk composition (%)				
Fat	4.0	4.0	4.1	3.9
Protein	2.9	3.0	2.9	3.0
Lactose	4.9	4.9	4.9	4.9

z Differences between protein levels are significant ($P<0.05$).
Adapted from Rae et al. (1983).

Table 14. Effect of acetic acid treatment on ruminal degradation characteristics of canola meal.

	Canola meal	
	Treated	Untreated
Dry matter (DM)		
Soluble (% of DM)	33.8a	26.2b
Degradable (% of DM)	53.5a	58.9b
Degradation rate (% h^{-1})	15.1a	6.1b
Effective degradability (%)	71.1a	55.4b
Crude protein (CP)		
Soluble (% of CO)	31.9a	18.1b
Degradable (% of CP)	62.9a	72.7b
Degradation rate (% h^{-1})	18.3a	5.4b
Effective degradability (%)	78.8a	51.9b

a, b Means in the same row followed by different letters are different ($P<0.05$).
Adapted from Khorasani et al. (1993).

Table 15. Effect of inclusion rate of acetic acid treated canola meal on milk yield and milk composition of mid lactation dairy cows.

	Replacement level[z] (%)			
	0	33	67	100
Dry matter intake (kg d^{-1})	19.7	20.6	20.6	19.6
Yield (kg d^{-1})				
Milk	24.8	25.1	25.7	25.0
Fat	0.9	0.8	0.8	0.8
Protein	0.8	0.8	0.8	0.8
Lactose	1.2	1.2	1.2	1.2
Composition (%)				
Fat	3.5	3.2	3.3	3.4
Protein	3.2	3.2	3.2	3.2
Lactose	4.8	4.8	4.8	4.8

z Replacement of untreated with treated canola meal.
Adapted from Kennelly and Khorasani (1993).

Table 16. Effect of inclusion rate of acetic acid treated canola meal on milk yield and milk composition of early lactation dairy cows.

	Replacement level		
	0	50	100
Dry matter intake (kg d^{-1})	20.4	21.2	20.3
Yield (kg d^{-1})			
Milk	28.6	30.4	30.8
Fat	1.1	1.1	1.1
Protein	0.9	1.0	1.0
Lactose	1.4	1.5	1.5
Composition (%)			
Fat	3.7	3.7	3.5
Protein	3.3	3.2	3.2
Lactose	4.7	4.9	4.8

Relacement of untreated with treated canola meal.
Adapted from Kennelly and Khorasani (1993).

Table 17. Effect of lignusulfonate (LSO_3) and xylose treatment of protein fractions of canola meal.

	Crude protein (CP)	Soluble protein (% of CP)	NDICP[z] (% of CP)	ADICP[y] (% of CP)	NH_3 (mg dL^{-1})
Untreated	37.4	22.4	16.8	6.7	4.0
1 h heat + H_2O	37.1	21.6	21.8	6.8	3.4
2 h heat + H_2O	37.9	19.4	24.1	6.5	2.5
1 h heat + 5% LSO_3	36.6	15.3	26.9	6.6	2.6
2 h heat + 5% LSO_3	37.7	13.1	34.4	7.6	2.0
1 h heat + 10% LSO_3	34.7	8.8	32.6	7.2	2.0
2 h heat + 10% LSO_3	35.7	8.5	45.6	12.4	1.3
1 h + 2% xylose	36.9	11.0	38.4	17.0	2.2
2 h + 2% xylose	36.8	7.7	47.9	22.5	1.4

z Neutral detergent insoluble protein.
y Acid detergent insoluble protein.
Adapted from McAllister et al. (1993).

Table 18. Effect of lignosulfobnate (LSO3) and xylose treatment of canola meal on crude protein ruminal kinetic parameters and effective degradability.

	Kinetic parameters			Effective degradability (%)
	Soluble fraction (%)	Degradable fraction (%)	Degradation rate	
Untreated	19.9	72.8	15.7	74.9
1 h heat + H_2O	18.5	74.9	12.8	72.3
2 h heat + H_2O	18.8	74.4	11.3	70.2
1 h heat + 5% LSO_3	15.0	78.8	9.0	65.5
2 h heat + 5% LSO_3	13.6	83.1	6.1	59.1
1 h heat + 10% LSO_3	12.6	84.5	6.3	59.5
2 h heat + 10% LSO_3	8.3	85.5	4.8	50.0
1 h + 2% xylose	15.0	76.9	7.5	61.0
2 h + 2% xylose	9.9	80.3	4.6	48.5

Adapted from Cheng et al. (1993).

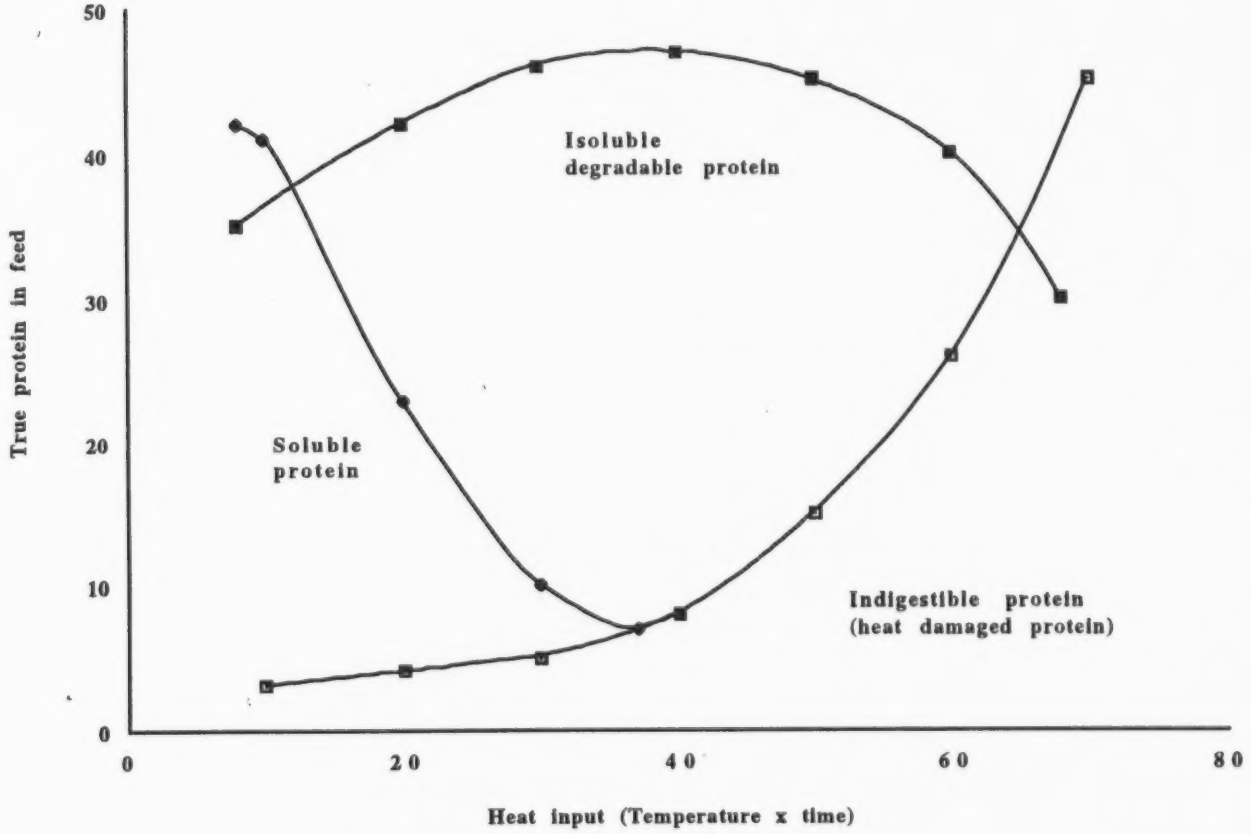

Figure 1. Influence of heat input on soluble, degradable and indigestible (heat-damaged) dietary protein.

(Van Soest, 1987).